CONTEMPORARY MATHEMATICS

200

Mathematical Problems in the Theory of Water Waves

A Workshop on the Problems
in the Theory of Nonlinear Hydrodynamic Waves
May 15–19, 1995
Luminy, France

F. Dias
J.-M. Ghidaglia
J.-C. Saut
Editors

American Mathematical Society

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These proceedings issue from a meeting held at CIRM (International Center for Research in Mathematics) in Luminy, France, on May 15–20, 1995, to review recent developments in the mathematical theory of water waves.

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Dedicated to
the memory of
T. Brooke Benjamin

Contents

Preface xi

An appreciation of T. Brooke Benjamin (1929–1995) xiii

List of participants xvii

List of lectures xxi

Radiation and modulational instability described by the fifth-order Korteweg-De Vries equation
IGOR BAKHOLDIN AND ANDREJ IL'ICHEV 1

Numerical simulation of singular solutions of the generalized Korteweg-deVries equation
J. L. BONA, V. A. DOUGALIS, O. A. KARAKASHIAN, AND W. R. MCKINNEY 17

Spatially quasi-periodic capillary-gravity waves
T. J. BRIDGES AND F. DIAS 31

On modulations of weakly nonlinear water waves
T. COLIN, F. DIAS, AND J.-M. GHIDAGLIA 47

Birkhoff normal forms for water waves
WALTER CRAIG 57

Remarks on the stability of generalized KP solitary waves
A. DE BOUARD AND J.-C. SAUT 75

On the asymptotic integrability of a generalized Burgers equation
A. S. FOKAS AND L. LUO 85

Spatial instabilities and chaos in high-order Hamiltonian standing water waves
M. GLOZMAN AND Y. AGNON 99

Solitary wave interactions for the fifth-order KdV equation
B. MALOMED AND J.-M. VANDEN-BROECK 133

Forced Benjamin-Ono equations and related topics
YOSHIMASA MATSUNO 145

Nonlinear evolution of water surface waves: The frequency down-shift phenomenon
C. SKANDRANI, C. KHARIF, AND J. POITEVIN 157

Solitary waves on the free surface of a rotating cylindrical flow
S. M. Sun 173

On a generalized Kadomtsev-Petviashvili equation
Michael M. Tom 193

A phenomenological description of soliton splitting during run up
E. van Groesen 211

Asymptotic stability of nonlinear bound states in conservative dispersive systems
M. I. Weinstein 223

Preface

Stemming from a familiar physical problem, the theory of water waves leads to a variety of difficult mathematical issues, involving several domains of mathematics: partial differential equations, dynamical systems, hamiltonian systems, numerical analysis, etc.

These Proceedings are issued from a meeting held at the CIRM (International Center for Research in Mathematics) in Luminy, France (May 15–20, 1995), which gathered around 40 applied mathematicians and physicists. The contributions therein review some of the recent developments in the mathematical theory of water waves. In particular the following aspects are considered: modelling of various wave systems, mathematical and numerical analysis of the full water wave problem (the Euler equations with a free surface) and of asymptotic models (Korteweg–de Vries, Boussinesq, Benjamin–Ono, Davey–Stewartson, Kadomtsev–Petviashvili, etc.), existence and stability of solitary waves.

This volume is dedicated to the memory of T. B. Benjamin (1929–1995), whose contributions to the theory of water waves are deep, durable and cannot be overestimated.

This meeting was made possible thanks to generous grants from the following French organisations: Ministère des Affaires Etrangères (Mission de l'Appui Scientifique et Technique), Ministère de l'Enseignement Supérieur et de la Recherche (Mission Scientifique et Technique, DSPT1), Centre International de Rencontres Mathématiques (Luminy), Direction des Recherches et Etudes Techniques, Centre National de la Recherche Scientifique (Sciences Physiques pour l'Ingénieur).

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An Appreciation of T. Brooke Benjamin (1929–1995)

On the eve of the commencement of this conference, Professor T. Brooke Benjamin was diagnosed with the cancer that claimed his life in August of 1995. It is appropriate for several reasons that this volume be dedicated to his memory.

First and foremost are Brooke's accomplishments in theoretical and experimental aspects of the study of fluid mechanics, including seminal work on water waves. Benjamin was among the very best scientists in the world in this active and important area, and held that place for most of the four decades his career spanned. Indeed, a reading of the corpus of his work puts him on a par with such earlier giants as G. I. Taylor and T. von Karman.

Secondly, though Brooke was not able to attend the conference in Luminy, I subsequently communicated the program to him. He read the abstracts from start to finish, and, in late July, we had a long conversation, which, in part, centered around the content of many of the lectures. As was his usual style, he was critically disposed toward my reporting of various of the ideas put forward in the meeting. Indeed, it was always a point in one's favour when Brooke took enough interest to comment. However, his overall opinion of the conference was that it must have been a huge success, especially as it brought together such a wide range of expertise and points of view.

Finally, Brooke's name appeared early and often in the lectures and discussions at the conference. His influence on the topics and the technical aspects of the Luminy conference was pervasive.

Benjamin hailed from Merseyside in the North of England. He read Electrical Engineering at Liverpool University not long after World War II. It is worth noting that he was apparently equally talented in his formal studies and in his musical pursuits. By the time he had reached the age of 20, he had written more than 100 complete pieces of music! A Rotary Club Fellowship took him to Yale University for a Master's degree, awarded in 1952. After his year's sojourn in Connecticut, during which he developed a life-long interest in American football, he matriculated in Cambridge University. He completed his Ph.D. there in 1955 under the direction of A. M. Binnie, and was immediately awarded a Fellowship in King's College. During this period, he wrote his first paper jointly with James Lighthill on periodic surface water waves and their application to understanding bore propagation. The paper has become a classic, and has been revisited many times by scientists all over the world, including Benjamin himself. In fact, one of his last published works settled a conjecture made some 40 years earlier in that paper. During the ensuing

15 years at Cambridge, Benjamin looked very deeply into important phenomena in fluid mechanics. His works during this period included novel experimental investigations of cavitation, especially its effect on solid boundaries, associated theoretical developments of stability of bubbles, his well-known theory of vortex breakdown, the famous Benjamin-Feir instability of periodic surface waves, the derivation and analysis of the so-called Benjamin-Ono equation, a comprehensive theory for flow in articulated pipes and, more generally, in containers with flexible boundaries, and his influential studies of flow of thin films down inclined planes. His work during this era of his life was recognized when, in 1966, he was elected a Fellow of the Royal Society of London, one of the youngest ever.

In the late 1960's, Brooke became enamoured of the powerful methods of nonlinear functional analysis being pioneered in France, Russia, and North America. He was especially intrigued by their potential for explication of general issues in fluid mechanics. The work of Krasovskii on periodic water waves, the work of Arnold on stability theory, the general theory of positive operators put forward by Krasnoselskii, the older work of Leray and Leray and Schauder, and a number of other works had a great influence on him during this period. He came to the view that fluid mechanics might benefit from a closer alliance of the classical theoretical and experimental studies with methods from modern mathematical analysis. This point of view accords very well with the philosophy shown by Dias, Ghidaglia, and Saut in organizing the present conference. Brooke noted this explicitly as he reviewed the conference abstracts with me in July 1995. Deciding that this point of view could best be developed away from a great center like Cambridge, Benjamin moved in 1970 to set up and become the director of the Fluid Mechanics Research Institute at the University of Essex.

Supported initially by a U.K. Science Research Council grant, Brooke's new center was already attracting world-wide attention in the early 1970's. As Brooke envisioned, it featured a first-class laboratory facility and a cadre of young experimentalists, theoreticians and mathematicians. In large measure because of Brooke's influence, this Institute saw an extraordinary range of collaboration among its members. In addition to putting together this new Institute, Brooke wrote several papers showing very clearly how well he had mastered some of the ideas from nonlinear analysis. His theory of stability of solitary waves was a seminal contribution, as was his work on conjugate flows in internal wave propagation. Later, he wrote a series of papers applying Leray-Schauder theory to problems of hydrodynamic stability. He followed these up with specific studies of steady flow problems for viscous fluids. While developing his skill with nonlinear analysis and its applications, he did not neglect the experimental side of the subject. While at Essex, he initiated a new laboratory study of the Taylor problem of flow between rotating, concentric cylinders and, in collaboration with Scott, he completed experiments on gravity-capillary waves in a narrow channel. He also supervised several students in experimental work at Essex. His choice of colleagues at Essex was good enough that some of the young folks Brooke had assembled were enticed elsewhere in due course. This should not have presented a problem since Brooke had an understanding with the Vice Chancellor and the Mathematics Department regarding continued support of his Institute; however, the support was not forthcoming. Eventually, the funding for the Institute fell below critical mass and Brooke moved on to Oxford.

In the fall of 1978, Brooke accepted the Sedleian Professorship of Natural Philosophy at Oxford, and a Fellowship at The Queen's College. He brought along Tom

Mullin at an early stage in his time at Oxford to help with setting up a laboratory facility, this time sited in the Physics Department. Benjamin and Mullin published an influential series of works on the Taylor flow, exposing aspects of the problem that had eluded earlier investigators. At a later stage, they also collaborated on work concerned with buckling instabilities of shear flows. At about the same time, Benjamin and a young post-doctoral fellow, Peter Olver, wrote a wonderful paper cataloging all the symmetries and associated conservation laws for the full, inviscid water-wave problem. He also brought an old fascination with soap films to a new level with a couple of very substantial papers with Cocker. Using pipe cleaners and washing-up liquid, Brooke on many occasions amused his friends and colleagues with his simple but effective demonstrations of the statics and dynamics of soap films. Building on his very early work, he also put forward a new Hamiltonian theory of bubble motion in an unbounded fluid. This latter paper was also partly an outgrowth of a long paper he wrote on one of his favorite themes, namely, the connection between impulse and flow force and the associated variational principles.

As he came up on the last decade of his career, Benjamin's range of inquiry stretched even further. For example, he worked on reflection of waves from ripply bottoms with Pritchard and Karakiewicz, and wrote a paper that was connected with work on wave-driven sediment motion and sand-bar formation, on a very general theory for the existence of solitary waves involving refined ideas from functional analysis with Bose and me, on the shape oscillations of bubbles, on gravity currents, more on Hamiltonian structure, and with Pritchard and Tavener on interesting low-Reynolds number free-surface flows. He revisited his theory of vortex breakdown, but with decidedly more sophisticated tools in his arsenal. Very recently, he put forward and partially analysed a new equation for solitary internal waves in situations where damping can be ignored, but surface tension cannot. He also wrote the aforementioned work on the Benjamin-Lighthill theory. During early 1995, he was hard at work on questions about damping of surface water waves in preparation for some experiments to be run at Penn State.

In 1991, Benjamin held forth in Orlando, Florida, at a National Science Foundation sponsored CBMS-lecture series. In a collection of ten lectures, he outlined his overall view of much of modern fluid mechanics. It was tough going for the audience, but there were many veins of gold revealed during this week-long conference. It is a great pity that Brooke never finished writing these lectures for publication.

Brooke Benjamin's work was formally celebrated many times during his productive career. As mentioned before, in 1966 he was elected a Fellow of the Royal Society of London and in the same year was presented with the L. H. Moody award by the American Society of Mechanical Engineers. In 1970, he received the Hopkins Prize from the Cambridge Philosophical Society. In 1989, a conference was convened at Penn State in honor of his 60th birthday. He was awarded honorary doctorates from the University of Bath, the University of Liverpool, and Brunel University. An accolade he very much appreciated was his election as a Foreign Member of the French Academy of Science in 1992. In 1994, Brooke was named Honorary Member of the American Society of Mechanical Engineers, their highest award.

Brooke supervised about 35 Ph.D. theses in his lifetime. Most of his students went on to substantial careers of their own. On the surface, he was tough and somewhat inaccessible to these students, but the real level of his concern for their development was always clear to his more senior colleagues. In addition, he acted

very successfully as a mentor for many post-doctoral level scientists. A full accounting of those on whom he had direct influence, including students, young associates and collaborators, would surely number more than 100.

Throughout his career, Brooke was concerned in a very substantive way with science policy. This was already apparent during his Essex years, but in the 1990's, when British government policy turned away from the development of science, Brooke helped to mount the U.K. National Conference of University Professors as a countervailing force. He served as its first President, and was the author of several closely reasoned essays on why the then-current policy was going awry. His feelings about such matters ran very deep.

I conclude this appreciation of Brooke Benjamin with some personal notes. In addition to his love of music, which never flagged throughout his life, he was deeply interested in mechanical things, especially steam locomotives. During the last decade of his life, he was attached to Penn State as a permanent Adjunct Professor in addition to his Chair at Oxford. In this position, he visited Penn State each fall for periods from one to three months.

During his stays there, we often trekked around the countryside to find steam locomotives to view. To his great delight, we even found a few that were in working order. At Penn State, he also indulged his love of American football, becoming one of the football team's ardent supporters. He always expressed in many, many ways a deep love and commitment to his wife Natalia and his young daughter Victoria. Above all else, they were the light of his world. He will be missed for his brilliance and insight, and for his taste in choice of problems to confront. He will be missed also for his technical expertise, his sage advice, and for his rigorous criticism and holding himself and others to the very highest standards. At a more prosaic level, we will miss long, philosophical discussions with him that went on far into the night. Perhaps most, we will miss the first sight of his tall angular frame in the late morning, the broad smile that creased his face, and the outstretched hand when he would greet a good friend.

Jerry Bona
Austin, Texas
1 July 1996

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List of Lectures

Y. Agnon, M. Glozman : *Standing Stokes waves - Are they stable?*

T. Akylas : *Nonlinear coupling of long waves with short-scale oscillations*

J. Albert, J. Bona, M. Rose, J.-C. Saut : *Model equations for waves in stratified fluids*

J. Bona : *Two-way propagation of nonlinear, dispersive waves*

A. de Bouard, J.-C. Saut : *Solitary waves of generalized Kadomtsev-Petviashvili equations*

T. Bridges : *Reappraisal and validity of the Whitham modulation theory*

P. Chossat : *1:2 mode interaction with O(2) symmetry and water waves*

T. Colin, F. Dias, J.-M. Ghidaglia : *On rotational effects in the modulations of weakly nonlinear water waves over finite depth*

W. Craig : *Normal forms for water waves*

V. Dougalis : *Numerical approximation of blow-up of solutions of some nonlinear, dispersive wave equations*

A. Fokas : *The KdV equation on the quarter plane*

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T. Miloh, A. Minzoni : *On the number of solitons for the ILW equation*

S. Pierini : *Coupled nonlinear wave models: applications to internal tides and tsunamis*

A. Ramamonjiarisoa, M. Joelson : *Random fields of water surface waves: a preliminary investigation*

H. Segur, J. Curry, B. Dubrovin, J. Hammack, D. MacCallister, N. Sheffner : *Waves in shallow water*

V. Shrira, S. Badulin, C. Kharif : *Model of water wave 'horse-shoe' patterns*

E. Soewono, S. van Gils : *Mode dynamics of perturbed Korteweg-de Vries equation*

M. Stiassnie : *On the equilibrium spectrum of gravity–capillary waves*

S.-M. Sun : *Solitary waves in stratified fluids of great depth*

L.-y. Sung : *Solving Davey-Stewartson equations by inverse scattering*

M. Tanaka : *On the crest instability of steep gravity waves*

J. Toland : *A plethora of solitary gravity–capillary water waves with nearly critical Bond and Froude numbers*

M. Tom : *On a generalized Kadomtsev-Petviashvili equation*

J.-M. Vanden-Broeck : *Numerical studies of solitary waves with vorticity and surface tension*

M. Weinstein : *Stability and instability in infinite dimensional conservative systems*

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